Controls for the KamLAND 4π Off-Axis Calibration System

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The KamLAND 4π off-axis calibration system will allow radioactive sources to be deployed to points throughout the detector's fiducial volume, enabling a more complete understanding of its response and a corresponding reduction in the associated systematic uncertainties. It includes a segmented pole that is suspended from two control cables, which are held together at a point by a pivot block to which one cable is fixed and on which the other is free to slide.

The KamLAND liquid scintillator is held in a Nylon/EVOH balloon that is suspended in a buffer of mineral oil. This balloon is rather delicate, and great care must be taken to avoid contact between it and the 4π system. Consequently, the positions of all components of the 4π system must be known at all times while it is in the detector. In addition, the position of the radioactive source must be measured as well as possible, generally to within a few centimeters, for an effective calibration.

The control system includes two brushless servo motors, each of which is coupled through a gearbox to a cable spool, as illustrated in Figure 1. Encoders integrated into the motors measure the number of revolutions of the cable spools. The amount of cable that has been dispensed can be calculated, assuming a model that describes how the cable winds on the spool. However, the primary position measurement is expected to come from encoder pulleys, which directly measure the amount of cable that has passed over them. Based on the cable lengths and other known geometrical parameters, the positions of all components of the system may be determined. As an additional cross-check, pressure transducers attached to each end of the pole and also to the pivot block will determine the depth at these locations. All of these methods will be used for continuous real-time monitoring. In addition, the positions of the pivot block and the ends of the pole will also be marked with 860 nm infrared LEDs. This wavelength can be seen by CCD cameras mounted around the detector, but it is invisible to the photomultipliers.

A number of layers of protection will be used to ensure the safe operation of the 4π control system:

- The deployment will proceed according to a formal, written protocol.
- The operator will be required by the control system to move in small steps, checking that the response is as expected.
- Each step will be verified by the control program against its model of the current position of the system before it is passed on to the motor controller. If a step would place any part of the system too close to the balloon, then it will not be started.

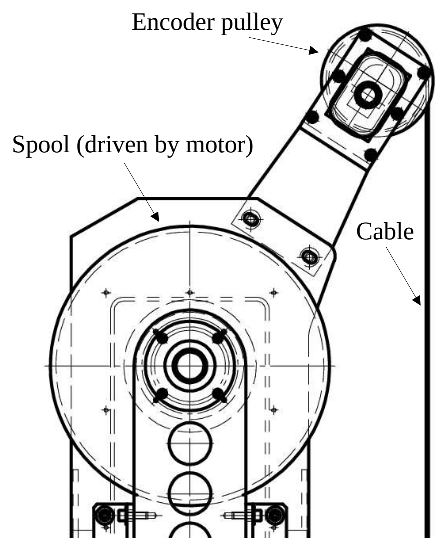

FIG. 1: Technical drawing illustrating the arrangement of the spool and encoder pulley for one cable.

- If the reconstructed position from the pulley encoders indicates that the system has unexpectedly moved outside of the allowed region, then all motion will be immediately stopped until the problem is resolved.
- The pulley encoder, motor encoder, and pressure transducer readings will be continuously cross-checked. If the positions reconstructed from these instruments become inconsistent (within a predefined tolerance), then motion will be stopped.

In 2003, the control system began its journey from conceptual design into reality. A formal deployment protocol was drafted and revised several times. The motors, encoders, drives, and controller were purchased and tested. The low-level software to communicate with all of this hardware was developed. In 2004, we anticipate that the 4π system will be completed, transported to the KamLAND site, and used to calibrate the detector. Consequently, the high-level control software will be finished, tested, and deployed together with the rest of the apparatus. This software will be written in Java and will be organized into a control program and a separate display program that communicate through a defined interface. The display program will show the current status of the system, including a visualization of the current position of the cables and pole.